SENSORY AND TEXTURE PROPERTIES OF MASHED POTATO INCORPORATED WITH INULIN AND OLIVE OIL BLENDS

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The effect of adding different ratios of inulin and extra virgin olive oil blends, formulated without (MPA) and with cryoprotectants (MPB), on texture properties of fresh mashed potatoes and frozen/thawed mashed potatoes was studied. Inulin and extra virgin olive oil behaved like soft fillers, but inulin was associated with increased fibrousness and extra virgin olive oil with increased creaminess. In the total dataset and frozen mashed potatoes, frozen/thawed mashed potatoes, and MPA subgroups, component 1 was a contrast between mechanical and surface textural attributes, whereas in MPB samples component 1 was determined by geometrical attributes. Addition of inulin at 30 g/kg and extra virgin olive oil at 45 g/kg is recommended.

Keywords: ***Mashed potatoes, Inulin, Extra virgin olive oil, Principal component analysis, Sensory properties, Back extrusion.***

INTRODUCTION

Recent changes in our lifestyles have led to an increasing demand for convenience foods, and our growing awareness of the relationship between food and health has increased the demand for higher-fiber, lower-fat products.[1] However, the addition of functional and nutritional food ingredients, such as inulin (INL) and/or extra virgin olive oil (EVOO), will produce perceptible differences in the sensory properties of mashed potatoes (MP). In most cases, INL has been added to different foods, in amounts ranging from 3 to 6 g per portion, to increase soluble fiber ingestion, or to assure bifidus production by adding 3–8 g per portion.[2] INL is also currently used in food formulations as a techno-functional agent for fat replacement, bulking, water retention, etc.[3] A fat-like texture can be achieved by increasing the INL concentration and average degree of polymerization above a critical

value.[4] In particular, long-chain INL can act as a fat mimetic due to its capacity to form microcrystals, which interact with one another to form small aggregates that occlude a large amount of water; thus creating a fine, creamy texture that gives a mouthfeel similar to that of fat.[5]

Olive oil is an important dietary component of Mediterranean countries, and EVOO has nutritional and sensory characteristics that make it unique. In November 2004, the US Federal Drug Administration (FDA) permitted the following claim on olive oil labels concerning "the benefits on the risk of coronary heart disease of eating about 2 tablespoons (23 g) of olive oil daily, because of the monounsaturated fat (MUFA) in olive oil."[6] It is expected that consumers can attain this daily intake from different olive oil-containing foods.

Technologically, the industry increasingly needs to be able to understand and control texture and is, therefore, willing to help promote more innovation and new product development. Today, texture is seen as a positive quality attribute denoting product freshness, excellent food preparation, and eating enjoyment.[7] Consequently, textural evaluation is an important step in assessing the functionality of food products. Sensory evaluation of foods and beverages is also important and is usually carried out using conventional techniques, such as descriptive analysis.[8] A sensory panel test was used to evaluate instrumental parameters and the sensory texture in cooked potatoes.[9] A sensory texture profile analysis uses trained assessors to describe and give quantitative texture measures of a given food. This is applied using standard rating scales, which provide a quantitative evaluation of the mechanical and other texture parameters by measuring qualitative and quantitative textural differences of similar samples. A sensory descriptive texture profile, including 13 sensory attributes (geometrical, mechanical, surface, and other residual characteristics), was developed for MP in which the panel produced reliable results for most of the attributes with respect to discriminative ability and reproducibility.[10]

Principal component analysis (PCA) is among the multivariate techniques that can be applied to extract relevant information from descriptive sensory trials. In the case of highly correlated data, typical of sets of food-quality measurements, PCA will typically lead to a small number of fused feature variables (the principal components), which are always orthogonal and often have a ready physical interpretation.[11] This reduction should aim at identifying those descriptors that are sufficient to describe the product, while at the same time avoiding characteristics that are difficult to quantify.

As an MP sample behaves like a high-volume-fraction dispersion, the addition of INL (extra dry matter) would be expected to result in a firmer product. However, there is little information on the sensory characteristics of INL and how it may be affected by interactions with other ingredients like starch or different kinds of hydrocolloids; nor is there information available on the effects of EVOO incorporation on the sensory characteristics of MP products. EVOO is a liquid material and, therefore, a system to which it is added would be expected to be softer whatever the concentration used. Therefore, MP formulation may be optimized not only to improve nutritional value but at the same time to gain more insights into the sensory properties of such systems.

The purpose of the present research was therefore: (1) to evaluate the effect of adding different ratios of INL/EVOO blends on the sensory properties and instrumental texture measurements of FMP and F/TMP formulated without and with added cryoprotectants (kappa-carrageenan and xanthan gum); (2) to reduce and explain the perceived texture by means of linear combinations of the sensory attributes using PCA. The reliability of the sensory properties and the panel consonance are also discussed in some detail.

MATERIALS AND METHODS

Materials

The potatoes used were fresh tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain). INL with the trade name Orafti®HP (BENEO-Orafti, Tienen, Belgium) was a "long-chain" INL with an average DP (total number of fructose or glucose units) ≥23 and purity of 99.5% (producer's data). EVOO (Carbonell, Sevilla, Spain) was chosen for addition to the MP. Kappa-carrageenan (κ-C) (GENULACTA carrageenan type LP-60) and xanthan gum (XG) (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). Five different I:EVOO blend ratios were added to the samples (15 g/kg (I)/45 g/kg (EVOO), 15:45; 30 g/kg (I)/30 g/kg (EVOO), 30:30; 45 g/kg (I)/15 g/kg (EVOO), 45:15; 30 g/kg (I)/45 g/kg (EVOO), 30:45; 45 g/kg (I)/30 g/kg (EVOO), 45:30). Additional samples without added ingredients (0:0 control), with 60 g/kg added I alone (60:0) and with 60 g/kg added EVOO alone (0:60) were also prepared for each type of MP and processing condition.

Preparation of MP Samples

Tubers were manually washed, peeled, and diced. MP were prepared in ~2000 g batches from: 1185 g of potatoes, 450 mL of semi-skimmed in-bottle sterilized milk (fat content, 15.5 g/kg), 300 mL of water, 15 g of salt (NaCl), and the corresponding EVOO concentration (0–60 g/kg), depending on the I:EVOO ratio, using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). In turn, the corresponding INL concentration (0–60 g/kg) was previously dissolved in 750 mL of water and milk at 70°C for 15 min and agitated with a magnetic stirrer at 600 rpm. MPs were prepared without and with added κ-C and XG (MPA and MPB samples, respectively). In the latter case, hydrocolloids (each at 1.5 g/kg) were added to the rest of the ingredients in dry powder form. All the ingredients were cooked for 35 min at 90°C (blade speed: 0.10× *g*).[10,12] The mash was ground for 40 s (blade speed: 80× *g*) and for 20 s (blade speed: 1000× *g*) and then immediately homogenized through a stainless steel sieve (diameter: 1.5 mm). Half of each fresh blend (FMP samples) was analyzed at once and the other half was frozen and subsequently thawed (F/TMP samples). Two repetitions of each composition were prepared in different weeks for randomization.

Freezing, Thawing, and Heating Procedures

MP samples were placed on flat-freezing and microwave thawing trays, and then frozen by forced convection with liquid nitrogen vapor in an Instron (Canton, MA, USA) programmable chamber (model 3119-05, −70/+250°C) at −60°C until their thermal centers reached −24°C.[13] After freezing, the samples were packed in polyethylene plastic bags, sealed under light vacuum (–0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and placed in a domestic freezer for storage at −24°C. Packed frozen samples were thawed in a Samsung M1712N microwave oven (Samsung Electronics S.A., Madrid, Spain) by heating for 20 min at an output power rating of 600 W. After thawing, the temperature reached at the product thermal center was measured in all cases (+75 ± 5°C). The temperature was then reduced to 55°C by placing the samples in a Hetofrig CB60VS water bath (Heto Lab Equipment A/S, Birkerød, Denmark) as this is the preferred temperature for MP consumption.[10]

Sensory Analysis

MP samples were subjected to texture profile analysis, modified to evaluate vegetable purees according to UNE 87025[14] and other relevant International Standards,[15] and then used to select and define the sensory attributes included in the profile. A panel of four assessors, previously trained according to the ISO guidelines[16] and with 8 years of specific experience assessing MP, evaluated the textural attributes of the samples. Descriptive panels usually have 8 to 12 assessors though they may have more, or as few as 4.[17] An important point to note here is that as it is the assessors themselves who are the measuring instruments in sensory analysis, it is necessary to confirm their efficacy by evaluating the consistency of their replies and their ability to distinguish differences.[18] In fact, attempts have been made to train and incorporate new members to the panel. In these cases, models of analysis of variance (ANOVA) have been performed with interactions for each attribute, including assessor and sample, as factors. The results showed significant effects of assessor $\times$ sample interaction, illustrating disagreement among the new assessors and the four earlier members in scoring the samples for a lot of attributes. Certainly, specific instructions regarding panel size are not appropriate because of the many factors that have to be considered.[17]

Profile attributes were classified into four groups (Table 1). Attributes are listed in order of perception according to ISO guidelines.[17] Note that for moisture and fibrousness, numbers in parentheses, (1) and (2), refer to the order of their perception in the mastication process. Samples were evaluated in duplicate in morning sessions (1:00 p.m.), every day for 64 days, and assessors were given four samples (about 20 g each) for scoring the attributes of each group in the texture profile. All of the samples were served at 55°C in white plastic vessels, and the sample temperature was reached and kept constant by placing the product in the Hetofrig CB60VS water bath (Heto Lab Equipment A/S, Birkerød, Denmark) prior to testing. For each sample, panelists evaluated the perceived intensity of the 13 attributes on 8 cm descriptive linear scales labeled at each anchor: (left anchor: 1 = "not detectable"; right anchor: 9 = "extremely intense"). To reduce fatigue, a rest period of 5 min was taken after scoring each sample.

Instrumental Texture Measurements

A back extrusion (BE) test was performed using a TA.HDPlus Texture Analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 300 N load cell.[19] During tests, MP samples were kept at 55°C by means of a temperature controlled Peltier cabinet coupled to a heat exchanger and a proportional-integral-derivative controller. For BE tests, a rig (model A/BE, Stable Micro Systems) was used consisting of a flat 45-mm diameter Perspex disc plunger that moved within a 50-mm inner diameter Perspex cylinder sample holder containing 50 $\pm$ 1 g of the MP sample. The product was extruded to a distance of 20 mm at a 2 mm/s compression rate. Recorded force time curves provided the maximum positive force of extrusion (BE firmness [N]) and the negative area of extrusion (BE viscosity index [N s]).[20] Texture measurements were performed in quadruplicate and results averaged.

Expressible Water

Expressible water (E_w) was measured by centrifugal force according to Eliasson and Kim.[21] Centrifuge tubes containing approximately 10 g of MP were centrifuged at

Table 1 List of descriptive terms and definitions used in the sensory analysis of mashed potatoes by the trained panel.

Descriptors	Definitions
Perceived before placing the sample in the mouth:	
Granularity, Gra	Geometrical textural attribute reflecting the size and shape of the particles (the terms "creamy, floury, lumpy, gritty, and grainy" are used to convey an ascending scale of particle size perception).
Moisture (1), Moi (1)	Surface textural attribute reflecting the absorption of water by the mashed potato (the most common terms are surface attributes: dry, moist, and wet).
Perceived at the time of placing the sample in the mouth:	
Stickiness, Sti	Mechanical textural attribute reflecting the effort required to separate the food from another surface (e.g., a spoon).
Denseness, Den	Geometrical textural attribute reflecting the degree of solidness or compactness of the sample.
Homogeneity, Hom	Geometrical textural attribute reflecting the degree to which the sample is free of particles or irregularities.
Moisture (2), Moi (2)	Surface textural attribute reflecting the water content of the mashed potato (the most common terms are body attributes: dry, moist, juicy, succulent, and watery).
Firmness, Fir	Mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of the mashed potato (the intensity is perceived as the level of force required to compress a sample between the tongue and palate).
Perceived upon preparing the sample in the mouth for swallowing:	
Cohesiveness, Coh	Mechanical textural attribute reflecting the effort required to reduce the mashed potato to a state suitable for swallowing, taking into account the potato's resistance to disintegration.
Adhesiveness, Adh	Mechanical textural attribute reflecting the effort required to separate the food from any surface inside the mouth (teeth, gums, palate); the intensity is perceived as the level of force required to separate the compressed sample from bucal surfaces (especially the palate) with the tongue.
Fibrousness (1), Fib (1)	Geometrical textural attribute reflecting the fiber content perceived during preparation of the sample in the mouth prior to swallowing.
Perceived during final and residual phases of the mastication process:	
Ease of swallowing, Eas	Property reflecting the ease with which the mashed potato is transferred to the back of the palate and swallowed.
Palate coating, Pal	Property reflecting the sensation of mashed potato remaining on the palate after swallowing or ingestion.
Fibrousness (2), Fib (2)	Geometrical textural attribute reflecting the fiber content perceived during actual swallowing or ingestion of the mashed potato, and the sensations perceived in the residual phase.

(1) and (2) refer to the order of moisture and fibrousness perception in the mastication process.

15,000 × g for 30 min in a Sorvall®, RC-5B apparatus (Global Medical Instrumentation, Inc., Clearwater, MN, USA). E_w was expressed as the percentage of liquid separated per total weight of sample in the centrifuge tube. Measurements were performed in quadruplicate and the results averaged.

Statistical Analyses

A three-way analysis of variance (ANOVA) with interactions was applied to evaluate how the three factors studied—INL:EVOO ratio, presence or absence of hydrocolloids, and performance or not of a freeze/thaw cycle—affected the sensory attributes and the instrumental texture measurements of the MP. A two-way ANOVA with interactions was applied to evaluate how the INL:EVOO ratio and freeze/thaw cycle affected the E_w of the products, and it was found that the E_w was always zero for all the MPB samples. Minimum significant differences were calculated using Fisher's least significant difference tests (95% for comparison of sensory attributes and 99% for comparison of instrumental parameters).

The dataset ($n = 256$) and the FMP ($n = 128$), F/TMP ($n = 128$), MPA ($n = 128$), and MPB samples ($n = 128$) were analyzed by PCA to investigate the interdependence of the sensory attributes via identification of new, uncorrelated variables. Statistical analyses were performed with Statgraphics® software version 5.0 (STSC Inc., Rockville, MD, USA).

RESULTS AND DISCUSSION

Influence of Composition and the Freeze/Thaw Cycle on Sensory Attributes of MP Samples

Table 2 shows the effects of the three factors studied on the scores awarded to the sensory attributes of the MP samples. Graphs of the sensory attributes for different binary interactions are shown in Figs. 1 and 2. Binary interactions were considered since their importance (F values) is mostly much higher than the triple interactions. All three main factors significantly ($P < 0.05$) affected the textural attribute scores with some exceptions, such as homogeneity and ease of swallowing scores, which were unaffected by cryoprotectant addition and the freeze/thaw cycle, respectively. The three binary interactions also had a significant effect on most sensory attribute scores, although only the INL:EVOO ratio, cryoprotectant addition (AB), the INL:EVOO ratio, and the freeze/thaw cycle (AC) interactions significantly affected granularity and ease of swallowing scores.

Attributes perceived before putting the sample in mouth. Figure 1a shows the variation in granularity based on the INL:EVOO ratio for both MPA and MPB samples. One can observe that, except for samples with an added 30:30 ratio, granularity scores were higher in the MPA samples. The presence of XG in the MPB systems reduced the grainy appearance by slowing or preventing starch retrogradation during the freeze/thaw cycle.[22–24] Brennan et al.[25] studied the pasting properties and freeze/thaw stability of natural waxy maize starches in the presence of XG using a Rapid Visco Analyzer and turbidimetric analysis. Freeze/thaw stability was determined after four cycles over a 4-week period during which XG reduced starch retrogradation and increased freeze/thaw stability. Arocas et al.[26] reported that gums, such as XG, affect the gelatinization and retrogradation of starch through strong associations with amylose, resulting in reduced amylose-amylose interactions. Visually, the texture of frozen/thawed MPA samples appeared to be spongy, stratified, and flaky, as reflected by the significant increase in granularity scores. This undesirable appearance was not observed in the MPB samples.

In both MPA and MPB samples, panelists judged granularity to be higher in samples with an added 60:0 ratio than in the 0:0 control, even though in the MPB products granularity scores in the samples with added 15:45, 30:30, 45:15, and 45:30 ratios were also significantly higher than those for the 0:0 control, and increased with increasing INL content. Furthermore, panelists found that samples with added 60:0 and 45:15 ratios had

Table 2 Effects of INL:EVOO ratio, cryoprotectant addition, and a freeze/thaw cycle on mean values of sensory attribute scores for the MP samples. Means and *F* values.

	Perceived before putting the sample in the mouth		Perceived at the time of putting the sample in the mouth					Perceived at the time of preparing the sample for swallowing			Perceived during the final and residual phases of mastication		
Sensory attributes	Granularity	Moisture (1)	Stickiness	Denseness	Homogeneity	Moisture (2)	Firmness	Cohesiveness	Adhesiveness	Fibrousness (1)	Ease of swallowing	Palate coating	Fibrousness (2)
Main effects:													
A: INL:EVOO ratio													
0:0 control	2.77^{c}	2.72^{e}	6.38^{a,b}	6.61^{a}	8.54^{a}	2.79^{d}	6.53^{a}	6.45^{a}	6.16^{a}	2.29^{c}	6.14^{f}	6.14^{d}	2.32^{b,c}
60:0	4.32^{a}	5.60^{a}	5.80^{c}	4.71^{f}	7.87^{c}	4.87^{a}	4.56^{e}	4.87^{c}	4.64^{c}	2.72^{a}	6.91^{e}	5.97^{d}	2.56^{a}
0:60	1.79^{f}	4.71^{c}	6.51^{a}	5.17^{c,d}	8.54^{a}	4.18^{c}	4.93^{c}	5.03^{c}	4.72^{b,c}	1.96^{d}	8.07^{c}	7.52^{a}	1.49^{e,f}
15:45	1.74^{f}	4.02^{d}	6.22^{b}	5.23^{c}	8.36^{b}	4.06^{c}	5.17^{b}	4.99^{c}	4.72^{b,c}	1.96^{d}	8.00^{c}	7.43^{a}	1.78^{d}
30:30	2.16^{e}	4.15^{d}	5.79^{c}	5.66^{b}	8.55^{a}	4.24^{c}	5.20^{b}	5.41^{b}	4.31^{d}	1.56^{e}	7.59^{d}	7.41^{a}	1.38^{f}
45:15	3.13^{b}	4.81^{c}	5.78^{c}	4.97^{d,e}	8.32^{b}	4.09^{c}	4.76^{c,d}	5.32^{b}	4.91^{b}	2.54^{b}	6.91^{e}	6.46^{c}	2.44^{a,b}
30:45	1.70^{f}	5.36^{b}	5.64^{c}	4.75^{f}	8.61^{a}	4.56^{b}	4.57^{d,e}	4.26^{d}	4.56^{c}	1.62^{e}	8.29^{a,b}	6.87^{b}	1.54^{e}
45:30	2.41^{d}	5.17^{b}	5.61^{c}	4.83^{e,f}	8.24^{b}	4.14^{c}	4.74^{c-e}	4.43^{d}	4.56^{c}	2.32^{c}	8.12^{b,c}	6.96^{b}	2.28^{c}
F values	235.62	135.42	20.17	73.56	18.63	11.60	81.55	70.73	57.51	87.06	121.14	61.41	88.12
B: Cryoprotectant addition													
MPA: Without κ-C and XG	2.88^{a}	5.99^{a}	4.67^{b}	3.88^{b}	8.40^{a}	5.01^{a}	3.70^{b}	3.94^{b}	3.30^{b}	2.30^{a}	8.01^{a}	6.54^{b}	2.12^{a}
MPB: With κ-C and XG	2.12^{b}	3.15^{b}	7.25^{a}	6.60^{a}	8.35^{a}	3.22^{b}	6.42^{a}	6.25^{a}	6.35^{a}	1.94^{b}	7.38^{b}	7.15^{a}	1.82^{b}
F values	334.49	2536.26	2187.64	2705.28	1.36	206.28	2912.99	1649.01	3332.61	130.82	154.41	127.51	70.39
C: Freeze/thaw cycle													
FMP: Freshly made samples	2.91^{a}	4.72^{a}	6.31^{a}	5.17^{b}	8.09^{b}	4.30^{a}	4.96^{b}	5.04^{b}	5.13^{a}	2.50^{a}	7.68^{a}	6.99^{a}	2.29^{a}
F/TMP: Frozen/thawed samples	2.10^{b}	4.41^{b}	5.62^{b}	5.31^{a}	8.67^{a}	3.94^{b}	5.16^{a}	5.15^{a}	4.52^{b}	1.74^{b}	7.71^{a}	6.70^{b}	1.66^{b}
F values	381.71	31.04	160.36	6.94	207.24	8.34	15.84	3.92	136.05	578.82	0.34	28.71	305.51
Interactions	*F* values												
AB	68.94	43.11	78.64	21.22	6.87	36.76	17.25	25.05	33.17	65.42	16.50	70.28	54.16
AC	103.88	26.05	51.80	14.15	12.23	31.19	27.85	9.28	22.04	56.98	22.07	23.52	58.56
BC	0.79	81.14	151.87	20.15	10.68	19.95	96.52	12.02	37.36	111.31	1.74	220.93	45.28
ABC	18	8.62	44.21	16.85	6.84	9.62	11.11	18.50	16.60	49.15	15.65	35.76	9.99

[a–f]Means for each textural attribute and for the same factor with common superscripts did not differ significantly ($P \geq 0.05$).

INL: inulin; EVOO: extra virgin olive oil; LSD: least significant difference; MP: mashed potatoes.

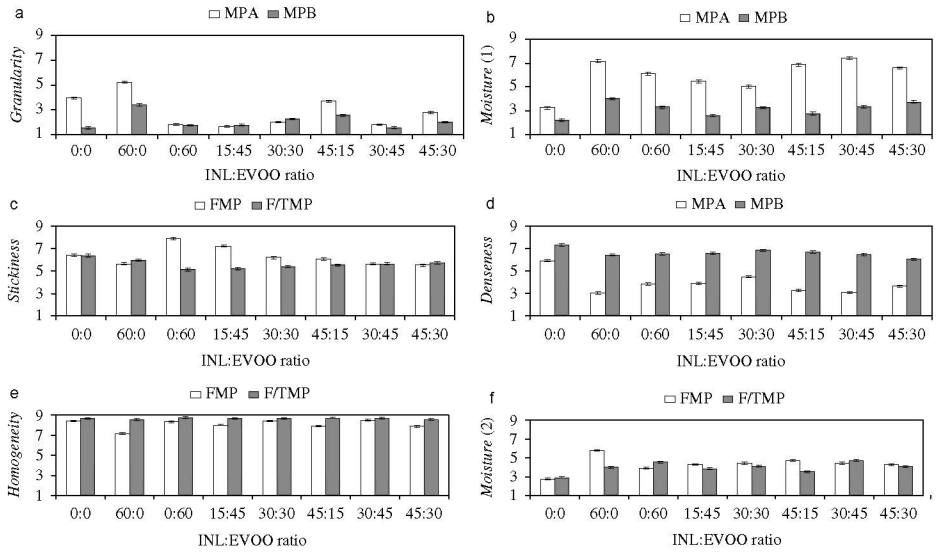

Figure 1 Sensory texture attributes scored by the trained sensory panel: (a) granularity; (b) moisture (1); (c) stickiness; (d) denseness; (e) homogeneity; (f) moisture (2). MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively; INL, EVOO: inulin and extra virgin olive oil.

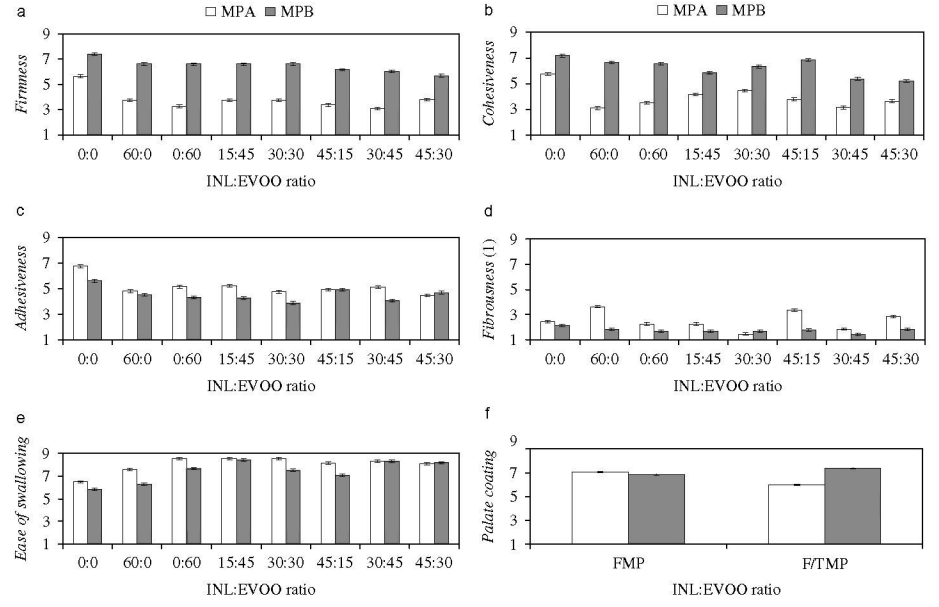

Figure 2 Sensory texture attributes scored by the trained sensory panel: (a) firmness; (b) cohesiveness; (c) adhesiveness; (d) fibrousness (1); (e) ease of swallowing; (f) palate coating. MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively; INL, EVOO: inulin and extra virgin olive oil.

a sandy texture associated with the presence of large INL crystals, which were even visible to the naked eye. The initial INL concentration may affect both the crystallization and aggregation processes and consequently the rate of sedimentation.[27] At 45 and 60 g/kg INL concentrations, the chains crystallize faster, which could explain the sedimentation detected in these samples. On adding long-chain INL some aggregates formed, embedded in a continuous network composed mainly of milk proteins with some immersed starch granules.[28] These aggregates were characterized by a rough outline, which could justify the significant increase in the perceived grainy appearance. On the contrary, at a fixed total concentration (60 g/kg), in both MPA and MPB samples, panelists judged granularity to be lowest in the samples with higher EVOO concentrations (0:60 and 15:45 ratios). Also, with a fixed INL content in both MPA and MPB samples, granularity scores decreased significantly with increasing EVOO content. These effects of EVOO on decreasing granularity are related to the lubricating and coating properties conferred by the oil as reported for vanilla custard desserts.[29]

Variation in moisture (1) based on the INL:EVOO ratios for both MPA and MPB samples are shown in the graph in Fig. 1b, and in all cases panelists detected increased aqueousness in the samples with added ingredients, whether alone or in associated blends. EVOO is a liquid material and, therefore, on adding EVOO, the systems would be expected to be moister whatever the concentration used. On the other hand, as MP samples behave like a high-volume-fraction dispersion, the addition of INL (extra dry matter) would be expected to result in a drier product. However, both ingredients appeared to produce a similar effect on this surface textural attribute. The INL long-chain structure resembles that of a network of fat crystals in oil, since this type of INL forms small microcrystal aggregates that occlude a considerable amount of water.[27] In fact, again in both MPA and MPB samples at a fixed EVOO concentration, moisture (1) scores increased linearly with INL content in all cases (15:45 versus 30:45 ratio and 30:30 versus 45:30 ratio), whereas at a fixed INL concentration, moisture (1) only increased linearly with EVOO concentrations in MPA (30:30 versus 30: 45 ratios) and MPB (45:15 versus 45:30) samples. Therefore, panelists detected that it was much easier to increase visual moisture (1) when INL was added to the systems. As suggested by Kim and Wang,[30] heating time probably induced INL hydrolysis, which in turn led to an increase in the reducing sugar concentration and probably caused a decrease in average polymer chain lengths. According to the latter authors, temperatures above 80°C under neutral conditions caused some degree of hydrolysis of dissolved highly-polymerized INL molecules, and long INL chains were probably degraded into smaller ones, which were unable to form a gel. Panelists also detected less aqueousness and, hence, a greater ability to hold water molecules in MPB samples. XG is an anionic, hygroscopic material of exceptional pseudoplasticity,[31] and its texturizing effect can be achieved at low gum concentrations because of its unusual water-holding ability.

Attributes perceived at the time of putting the sample in the mouth. The variation in stickiness scores determined by the INL:EVOO ratio in both FMP and F/TMP samples shown in Fig. 1c, indicates that stickiness was significantly higher in the fresh samples than in those subjected to a freeze/thaw cycle when EVOO was added either alone (0:60 ratio) or blended with INL at increasing concentrations. Though EVOO behaves like a soft filler suspended in a rigid matrix, it still confers stickiness to the product, which may be related to the coating properties of the oil.[29] In the F/TMP samples, panelists judged stickiness to be lower in the systems with added INL:EVOO ratios than in the 0:0 control.

The panelists also detected higher denseness in both MPA and MPB samples without either added INL or EVOO (Fig. 1d). In all cases, denseness scores were significantly

higher in the MPB than in the MPA samples; this result is attributed to the gelling properties of the κ-C as reported previously.[12] At a fixed total concentration, denseness scores were lower in the MPA samples with only added INL (ratio 60:0) than in those with only added EVOO (ratio 0:60). According to Carriere,[32] the transition from dilute to semi-dilute solution behavior in polymers is designated as c^*, and the results seem to indicate that INL did not reach the c^* concentration even at the highest concentration used in this study (60 g/kg). In the MPA samples, panelists judged denseness to be highest in the samples with an added 30:30 ratio, indicating the positive synergistic effect of the two ingredients. Homogeneity scores were higher in the F/TMP samples than in their FMP counterparts (Fig. 1e), and the I:EVOO ratio affected homogeneity much less in the F/TMP samples than in their fresh counterparts. All this suggests that the effect of I addition on the presence of irregularities in the MP samples is negative at higher fructan concentrations, although this effect is counteracted by a freeze/thaw cycle.

In comparison with 0:0 control, panelists detected greater moisture (2) in both FMP and F/TMP systems with added INL/EVOO blends (Fig. 1f), as in the case of moisture (1). The panelists also detected increased aqueousness in the FMP samples with added blend ratios of 60:0 and 45:15. Sensory firmness assessment confirmed that both INL and EVOO behave like soft fillers, with olive oil suspended and INL entrapped in a continuous phase (amylose/amylopectin matrix) due to the disruption and complete solubilization of the potato starch granules. At a fixed total concentration (Fig. 2a), there were non-significant differences between the firmness scores of the MPB samples with addition ratios of 60:0, 0:60, 15:45, and 30:30 as well as between the firmness scores of the MPA samples with addition ratios of 60:0, 15:45, and 30:30. This suggests that at the same concentration both ingredients produced a similar effect on the thickness of the samples. Nevertheless, at fixed EVOO and INL concentrations the decrease in firmness when both INL and EVOO concentrations were increased was more significant in the case of the MPB samples (ratios of 15:45 versus 30:45 and 30:30 versus 45:30) and (ratios of 30:30 versus 30:45 and 45:15 versus 45:30), respectively.

Attributes perceived at the time of preparing the sample in the mouth for swallowing. The variations in cohesiveness and adhesiveness scores for INL:EVOO ratios of both MPA and MPB samples as well as FMP and F/TMP samples are shown in Figs. 2b and 2c, respectively. At a fixed total concentration, cohesiveness scores were higher in the MPA samples with addition ratios of 15:45, 30:30, and 45:15, and lower with ratios of 0:60 and 60:0. These results suggest that in the MPA samples synergism between EVOO and INL also positively affected cohesiveness when they were added in associated blends, as compared to the scores awarded when they were added singly (ratios of 60:0 and 0:60). On the other hand, cohesiveness scores were lower in the MPB samples with addition ratios of 15:45 and 30:30 than in those with ratios of 0:60 and 60:0, supporting the hypothesis that the presence of cryoprotectants masked the effect produced by INL:EVOO ratio variations on the cohesiveness of these samples. Moreover, at fixed EVOO and INL concentrations, cohesiveness decreased linearly in both MPA and MPB samples with increasing INL and EVOO concentrations. In the FMP samples, at a fixed total concentration, adhesiveness scores were higher in the samples with higher EVOO concentrations (0:60 and 15:45 ratios) (Fig. 2c), although there were non-significant differences among the adhesiveness scores of the FMP samples with addition ratios of 60:0, 30:30, and 45:15. This again indicates that both ingredients produced a very similar effect on adhesiveness. However, in the F/TMP samples, at a fixed total concentration, panelists judged adhesiveness to be highest in the samples with lower EVOO concentrations (ratios of 60:0 and 45:15).

Fibrousness (1) scores increased with respect to 0:0 control when INL was added alone and when EVOO was added at a concentration of 15 g kg^{-1} (45:15 ratio), but decreased with increasing EVOO content, with cryoprotectant addition and with processing (Table 2). These variations in the fibrousness (1) score for the INL:EVOO ratio in both FMP and F/TMP samples (Fig. 2d) shows that, except for the samples with an addition ratio of 30:30, fibrousness (1) was significantly lower in the F/TMP samples than in the FMP ones. This result is probably related to the presence of XG in the MPB frozen/thawed systems, which reduced fibrousness (1). Hydrocolloids can make rubbery systems more viscous, reducing molecular mobility and preventing retrogradation.[22,23] Furthermore, at a fixed total concentration there were no significant differences between the fibrousness scores of the F/TMP samples. On the other hand, fibrousness (1) scores were significantly higher in the FMP samples with higher INL contents (60:0 and 45:15 ratios). Kim et al.[4] found differences in INL particle sizes between low shearing, high shearing, and thermally induced gels. The average particle size of INL crystals varied from 30 μm for low-shear-induced gel to approximately 2 μm for thermally induced gels. Changes in the particle distribution were also observed with the apparition of new particles (<10 μm) that were ascribed to INL crystal aggregates formed during the continuous phase of the system. According to this information, the increase in fibrousness (1) perceived for samples with higher I contents could be explained by the presence of large INL crystal aggregates.

Attributes perceived during final and residual phases of mastication. Variations in the ease of swallowing scores for INL:EVOO ratios of both MPA and MPB samples (Fig. 2e) show that in both types the scores increased when INL and EVOO were present, whether added singly or in blended samples. However, at a fixed total concentration, the ease of swallowing scores were higher in both MPA and MPB samples with lower INL concentrations (0:60, 15:45, and 30:30 ratios). Fat is a well-known enhancer of the creaminess sensation,[29] coating the oral tissues and thereby reducing the friction between food and tissue. In this study, the main differences between samples with and without added EVOO were ascribed to either an aromatic or a creamy mouthfeel detected in the MP samples with added oil, with or without I. On the other hand, except in the samples with addition ratios of 15:45, 30:45, and 45:30, the MPA samples scored higher for ease of swallowing (Fig. 2e). This result was probably related to excessive thickening perceived by the panelists in the samples containing cryoprotectants. The effect of κ-C on product thickening could also be ascribed to the interaction of κ-C with denatured milk protein.[12] The panelists also gave significantly higher scores for palate coating to samples with added EVOO than for those without added EVOO (Table 2). Palate-coating scores for MPA samples decreased after a freeze/thaw cycle, whereas the scores for MPB samples increased after processing with respect to the scores awarded to fresh products (Fig. 2f). This was probably due to softening in MPA and hardening in MPB samples after freezing and thawing processes. As a high correlation was found between the sensory attributes fibrousness (1) and fibrousness (2), graphs for fibrousness (2) scores have been omitted.

Principal Component Analyses (PCAs) of Sensory Scores

Abbreviations for sensory attributes, as shown in Table 1, are used in this subsection mainly for the sake of brevity. As the method proposed by Dijksterhuis[33] was used to evaluate panel consonance, an independent PCA was carried out of the total dataset ($n = 256$) for each attribute (4 panelists and 64 samples) obtained from the conventional profile. High consonance coefficients (the ratio between the first eigenvalue and the sum

of the others) indicate one-dimensional solutions or, in other words, that the panelists use the attribute in a similar way. Some differences were found between attributes. With four attributes (Sti, Adh, Eas, and Pal) the solutions were multidimensional, with low consonance coefficients (0.58, 0.64, 0.55, and 0.53, respectively) and with the second eigenvalue almost as high as the first one. Moi (1) and Coh showed medium consonance coefficients (0.78 and 0.75, respectively). For the remaining seven attributes, the consonance coefficients were high and the second eigenvalue was considerably lower than the first one. The highest coefficients were recorded for Fib (1) and Fib (2) (0.97 and 0.86, respectively). All of this suggests an acceptable level of consonance between panelists although more training in the use of Sti, Adh, and residual attributes (Eas and Pal) could improve the results.

Table 3 shows the two components extracted in each PCA analysis (total dataset and FMP, F/TMP, MPA, and MPB subgroups considered separately) for all of the 13 sensory attributes. The eigenvalues of the third component were lower than 1.0 in all the cases. Figures 3 and 4 show the biplots of the two principal components for the sensory attributes. PCA revealed that two principal components accounted for >74% of the total variability (Table 3) when all the data were included in the PCA analysis (Fig. 3), whereas the total variability explained by the first and second axes was slightly higher (>75%) when FMP and F/TMP samples were considered (Figs. 4a and 4b) separately, and slightly lower (<72%) when MPA and MPB samples were considered (Figs. 4c and 4d) independently.

Table 3 also gives the weights of the linear combinations that make up the two principal components. Sensory attributes with the highest loadings for each component are marked in boldface, indicating that this component is dominated by these particular attributes. When the 13 attributes were taken into account for all the data, including all experimental conditions (Fig. 3), Sti, Den, Fir, Coh, and Adh weighted component 1 negatively, whereas Moi (1) and Moi (2) weighted the first component positively. Therefore, the most important attribute variations were shown by MP samples to be low values for both mechanical (stickiness, firmness, cohesiveness, and adhesiveness) and geometrical (denseness) properties contrasting with high surface property values (moistures (1) and (2)). Adhesive MP samples had low moistness, which is common in potato textures.[34] Component 1 was mainly a contrast between the mechanical (Sti, Fir, Coh, Adh) and surface texture attributes (Moi (1), Moi (2)), and acted as an index of the mechanical behavior and moistness of the product. On the other hand, intercorrelated sensory attributes with nearly equal loadings were assumed to represent some redundancy. Den, Fir, and Coh, in particular, had nearly equal loadings, and Moi (1) and Moi (2) explained the same characteristic.

Component 2 was positively weighted by Hom, Eas, and Pal and negatively dominated by Gra and both Fib (1) and Fib (2). This means that when the panelists detected more granularity and fibrousness, they detected poorer homogeneity, ease of swallowing, and palate coating. Component 2 integrates four geometrical attributes (Gra, Hom, Fib (1) and Fib (2)) associated with the arrangement of particles in the product, and surface roughness or smoothness properties of MP texture according to Szczesniak.[7] Hence, component 2 may be identified mainly with geometrical and residual textural attributes, which serve as an index of the roughness/smoothness of the MP samples. Note that, although Den is a geometrical attribute, it correlated strongly with two mechanical properties (Fir and Coh). This indicated that the panel had difficulty distinguishing between force (Coh)

Table 3 Principal component analyses and equations of the principal components of the five PCA analyses carried out.

	All total dataset		FMP samples		F/TMP samples	
Component number	Eigenvalue percent of variance		Eigenvalue percent of variance		Eigenvalue percent of variance	
1	6.36	48.94	6.19	47.58	7.16	55.06
2	3.29	25.30	3.90	30.03	2.64	20.33
	MPA samples		MPB samples			
	Eigenvalue Percent of variance		Eigenvalue Percent of variance			
1	5.13	39.48	4.87	37.43		
2	4.17	32. 80	3.13	24.10		

	All total dataset		FMP samples		F/TMP samples	
	Component 1	Component 2	Component 1	Component 2	Component 1	Component 2
Gra*	0.19	**−0.41**	0.2	**−0.38**	0.19	**0.46**
Moi (1)	**0.36**	0.05	**0.37**	−0.02	**0.33**	−0.18
Sti	**−0.3**	−0.1	**−0.33**	0	**−0.29**	0.1
Den	**−0.37**	−0.11	**−0.38**	−0.13	**−0.35**	0.08
Hom	−0.1	**0.37**	−0.09	**0.34**	−0.09	−0.04
Moi (2)	**0.35**	0.01	**0.35**	−0.06	**0.32**	−0.2
Fir	**−0.37**	−0.09	**−0.37**	−0.1	**−0.36**	0.09
Coh	**−0.36**	−0.14	**−0.36**	−0.15	**−0.35**	0.1
Adh	**−0.34**	−0.2	**−0.36**	−0.16	**−0.34**	0.1
Fib (1)	0.16	**−0.44**	0.1	**−0.43**	0.27	**0.33**
Eas	0.17	**0.32**	0.14	**0.35**	0.17	**−0.4**
Pal	−0.14	**0.3**	−0.04	**0.41**	−0.22	**−0.4**
Fib (2)	0.15	**−0.46**	0.13	**−0.43**	0.16	**0.5**
	MPA samples		MPB samples			
	Component 1	Component 2	Component 1	Component 2		
Gra	−0.05	**0.44**	**0.36**	0.14		
Moi (1)	**0.37**	0.13	**0.34**	−0.09		
Sti	−0.07	−0.26	0.13	**0.46**		
Den	**−0.4**	−0.06	−0.24	0.29		
Hom	−0.05	**−0.35**	**−0.37**	−0.01		
Moi (2)	**0.34**	0.19	0.25	−0.08		
Fir	**−0.41**	−0.03	**−0.3**	**0.3**		
Coh	**−0.38**	−0.08	−0.11	**0.44**		
Adh	**−0.39**	−0.03	0.12	**0.41**		
Fib (1)	0.27	**0.44**	**0.38**	0.09		
Eas	0.11	**−0.29**	0	**−0.44**		
Pal	0.11	**−0.29**	−0.28	−0.07		
Fib (2)	−0.12	**0.43**	**0.38**	0.1		

*Identification of sensory attribute abbreviations in Table 1.

Sensory attributes with the highest loadings for each component are in boldface.

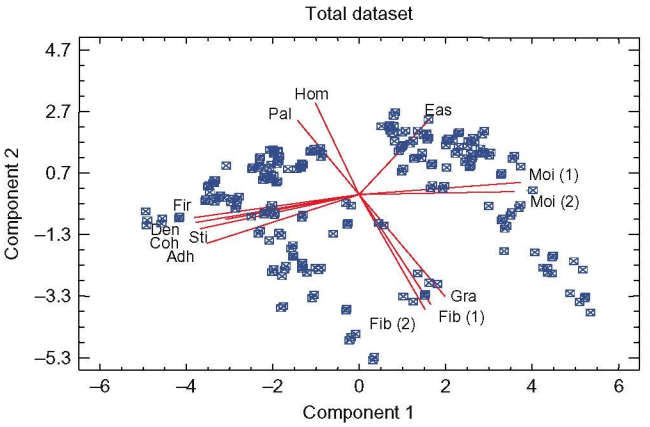

Figure 3 Biplot for the first two principal components from the principal component analysis (PCA) carried out for the full dataset. Identification of sensory attribute abbreviations in Table 1. (Color figure available online.)

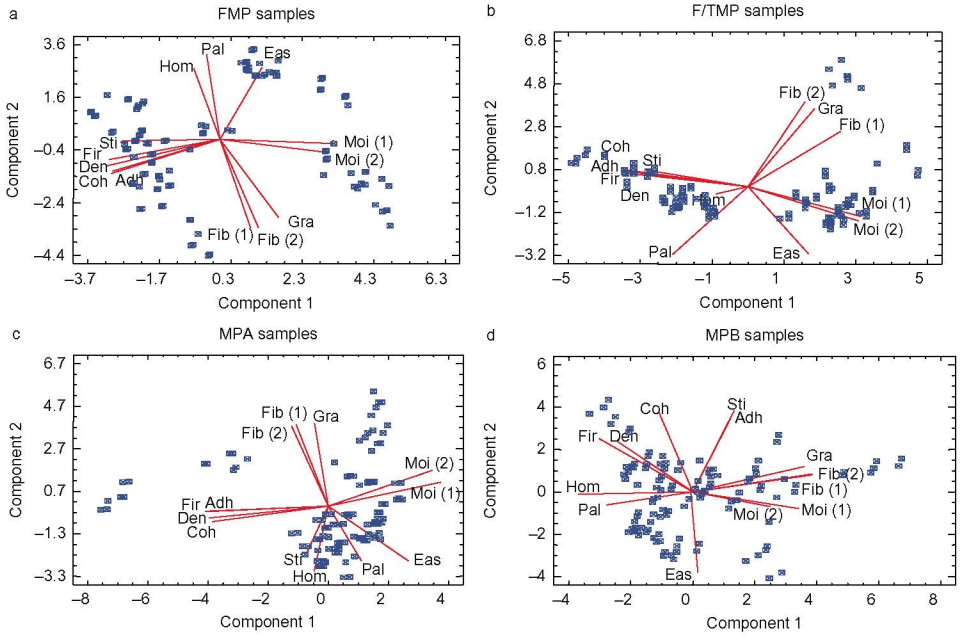

Figure 4 Biplots for the first two principal components from principal component analyses (PCAs) carried out for: (a) FMP samples; (b) F/TMP samples; (c) MPA samples; (d) MPB samples. FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively; MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively. Identification of sensory attribute abbreviations in Table 1. (Color figure available online.)

and deformation (Fir) of the mechanical properties and between solidness (Den) of the geometrical ones. The level of representation of an original attribute in the first and second principal component planes (Fig. 3) can be measured by means of the cumulative determination coefficient, defined as commonalities (data not shown). Firm, Coh, and Adh,

in that order, were the most important of the mechanical sensory attributes, explained to a great extent by the first two principal components, whereas geometrical Hom and residual Eas and Pal were only explained to a fairly moderate extent (with low percentages).

It is worth noting that when considering only FMP samples, both components are dominated by the same sensory attributes (Fig. 4a, Table 3). In this case, geometrical Den and mechanical Adh were the attributes best explained by the two components, whereas explanation percentages for Hom and Eas were the lowest. Then again, if we consider F/TMP samples separately (Fig. 4b, Table 3), Sti, Den, Fir, Coh, and Adh also negatively weighted component 1, whereas it was positively weighted by Moi (1) and Moi (2), the same as in the PCA analyses with the complete dataset and with FMP samples; MP samples had high moistness but low levels of Sti, Den, Fir, Coh, and Adh. However, Eas and Pal strongly weighted component 2 negatively, which in this case, was positively dominated by Gra and Fib (2). MP is a starchy food and as such may present quality problems, such as syneresis, organoleptic, and textural changes, especially if subjected to freeze-thaw cycles. These problems have been ascribed to phase separation caused by starch retrogradation.[21] Therefore, this change in the sign of the sensory attributes weighting component 2 is likely related to starch retrogradation caused by the freezing process in the products without added cryoprotectants, and consequently the panelists gave them higher scores for granularity and fibrousness. Of the mechanical attributes, Fir was the one best explained by the first two principal components and may, therefore, be considered the best suited to evaluate MP texture in the F/TMP samples.

In the case of the MPA samples (Fig. 4c, Table 3), again Moi (1) and Moi (2) positively weighted the first component, whereas it was weighted negatively by Den, Fir, Coh, and Adh. Also, as in the F/TMP samples, Gra, Fib (1), and Fib (2) positively weighted the second component, whereas it was negatively weighted by Hom, Eas, and Pal. Curiously, Fib (1) was the most important sensory attribute in this case, explained to a great extent by the first two components. This result, therefore, confirms that the absence of κ-C and XG in the frozen/thawed systems increased visual granularity.

However, if we consider the MPB samples separately (Fig. 4d, Table 3) we find a change in the correlations of the sensory attributes with both components, probably due to a reduction or absence of starch retrogradation. As mentioned above, gums like XG affect starch gelatinization through strong associations with amylose, resulting in reduced starch retrogradation.[26] Gra, Moi (1), Fib (1), and Fib (2) positively weighted component 1, whereas it was negatively weighted by Hom in particular; this factor is negatively dominated by Hom and almost equally weighted on the Gra, Fib (1), and Fib (2) ratings. Hence, component 1 is identified in this case with the geometrical attributes detected either before putting the sample in the mouth or during the final and residual phases of mastication, serving as an index of the roughness/smoothness of the MP samples. Also, Sti, Coh, and Adh, in particular, positively weighted component 2, though this factor was negatively dominated by Eas. In the MPB samples, component 2 was mainly a contrast between the mechanical texture attributes of the MP samples perceived during chewing versus residual ease of swallowing. MP samples with high levels of Coh, Sti, and Adh had low Eas. Here again, Fib (1) and Fib (2) had equal loadings (Table 3) as they explained the same characteristic. In the MPB samples, Fib (2), Fib (1), and Sti were the sensory attributes best explained by the two components (in that order). Certainly, new PCA analyses were run when redundant attributes were eliminated in any analysis, but these data are not shown for the sake of brevity. The main point of interest is that Fib (2) and Moi (2), in particular, could be removed with only a small percentage loss of information.

Influence of Composition and a Freeze/Thaw Cycle on Instrumental Texture Measurements and E_w of MP Samples

Table 4 shows the effects of the INL:EVOO ratio, cryoprotectant addition and a freeze/thaw cycle on the values of the instrumental texture measurements derived from the BE tests and E_w values. The analysis of variance showed that the three factors under consideration and their binary interactions had a significant effect on both instrumental texture measurements. This means that the effect of the INL:EVOO ratio on instrumental texture was dependent on the presence of κ-C, XG, and a freeze/thaw cycle. Plots for the BE viscosity index have been omitted for the sake of brevity.

Maximum instrumental texture values were registered in a 0:0 control (Table 4). By adding 60 g/kg of INL alone (60:0 ratio) all the instrumental measurements were significantly reduced when compared with the 0:0 control, whereas adding 60 g/kg of EVOO alone (0:60 ratio) significantly reduced instrumental BE firmness as compared to the addition of 60 g/kg of INL alone. This indicates that EVOO addition alone produced softer systems than INL addition alone. However, variations in the BE firmness value based on the INL:EVOO ratios in both MPA and MPB samples (Fig. 5a) show that in all cases (except for 0:0 control) BE firmness was lower in the MPA than in the MPB samples; moreover, the

Table 4 Effects of INL:EVOO ratio, cryoprotectant addition, and a freeze/thaw cycle on mean values of instrumental texture measurements and expressible water for the MP samples. Means and *F* values.

Source	BE firmness (N)	BE viscosity index (N s)	E_w (%)
Main effects:			
A: INL:EVOO ratio			
0:0 control	7.04^{a}	-37.06^{a}	17.32^{e}
60:0	5.17^{b}	$-23.65^{b,c}$	28.91^{a}
0:60	4.67^{d}	$-23.16^{c,d}$	16.20^{e}
15:45	$4.83^{c,d}$	-24.59^{b}	20.60^{d}
30:30	4.92^{c}	$-23.92^{b,c}$	20.35^{d}
45:15	5.19^{b}	-24.66^{b}	25.68^{b}
30:45	4.21^{e}	-20.65^{e}	19.50^{d}
45:30	4.61^{d}	-22.65^{d}	23.63^{c}
F values	212.59	290.46	164.39
B: Cryoprotectant addition			
MPA: without κ-C and XG	4.64^{b}	-21.28^{b}	—
MPB: with κ-C and XG	5.52^{a}	-28.73^{a}	—
F values	460.78	1265.80	—
C: Freeze/thaw cycle			
FMP: freshly made samples	5.50^{a}	-25.60^{a}	26.09^{a}
F/TMP: frozen/thawed samples	4.66^{b}	-24.41^{b}	16.96^{b}
F values	419.24	32.35	1489.97
Interactions	*F* values		
AB	34.25	29.32	—
AC	10.95	10.15	22.02
BC	932.54	817.12	—
ABC	10	22.03	—

Means for each instrumental measurement and for the same factor with common superscripts did not differ significantly ($P \geq 0.01$).

INL: inulin; EVOO: extra virgin olive oil; LSD: least significant difference; MP: mashed potatoes.

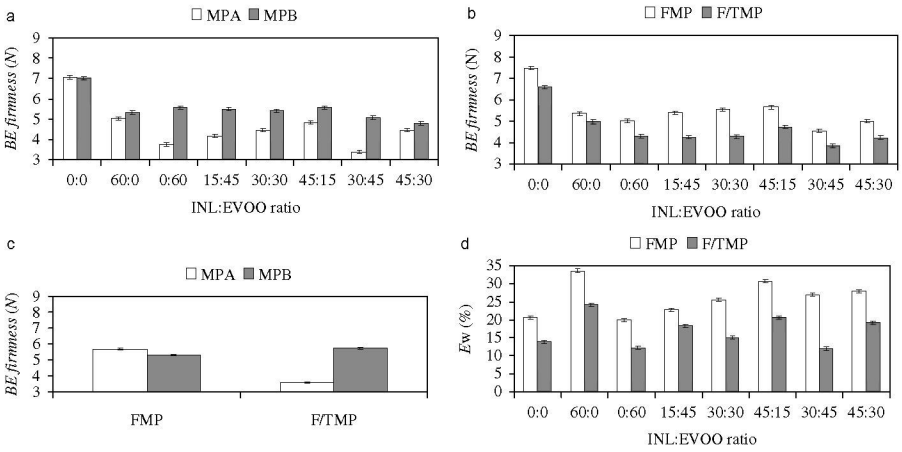

Figure 5 Instrumental texture measurements and expressible water: (a–c) back extrusion (BE) firmness; (d) expressible water (E_w). MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively; INL, EVOO: inulin and extra virgin olive oil.

variation in the firmness of the samples with both ingredients was much greater in the case of the MPA samples. Only MPB samples with addition ratios of 30:45 and 45:30 (at a higher total concentration, 75 g/kg) had significantly lower BE firmness values than those with a lower fixed total concentration (60 g/kg). The presence of hydrocolloids resulted in an improved, more solid, reinforced three-dimensional network structure, possibly through the exclusion effect of swollen starch granules promoting κ-C gelation in the aqueous phase. κ-C provided the appropriate texture, while XG imparted creaminess to the product.[12] Analogously, in starch/XG blends, it was observed that XG does not interfere with potato starch network building.[35,36]

The differences in BE firmness values between MPA and MPB samples were lower when INL was added at the higher concentrations (60:0, 45:15, and 45:30 ratios). Therefore, in the absence of κ-C and XG, INL addition at concentrations above 45 g/kg (either alone or blended with EVOO) produced a thickening effect on the MP as compared to I addition at lower concentrations. It is possible that in MPA samples, the structure of the MP was thickened due to the high INL concentration, because the system had enough particles and/or sufficient molecular INL chain density to reach a critical crowding effect.[4,30] This speculation is in agreement with the microstructure observed in INL-EVOO-based MP samples,[37] where amylose/amylopectin form a rigid matrix in which I particles are trapped. Guggisberg et al.[38] showed that even though firmness and creaminess of low-fat set yogurt increased with both INL and fat content, the highest level of INL considered (4%) was not enough to imitate the whole-milk yogurt. In turn, Villegas et al.[5] observed that low-fat milk beverages with a similar thickness and creaminess to those perceived in whole-milk beverages could be obtained by adding long-chain INL at a concentration above 8%. Of the MPA samples with added INL:EVOO, the ones with the lowest EVOO concentration (45:15 ratio) were firmest (Fig. 5a). At a fixed EVOO concentration, the firmness of the MPB samples decreased significantly with increasing INL concentrations (15:45 versus 30:45 and 30:30 versus 45:30 ratios); whereas at a fixed INL concentration, the addition of EVOO at higher concentrations considerably reduced BE firmness in both MPA and

MPB samples (30:30 versus 30:45 and 45:15 versus 45:30 ratios). Both ingredients caused softening of the MP samples, but when they were added in blends, the degree of softening was more dependent on EVOO concentration. In oil/water emulsions, the extent of the linear region has been reported to decrease with increasing oil-phase volume fraction from 20 to 40% v/v.[39]

When INL/EVOO blends were added to MP, the BE firmness value behaved similarly in the FMP and F/TMP samples (Fig. 5b). In natural MP, the product was also softer than the fresh control after freezing and thawing.[10] When compared with samples with added INL alone, the differences in firmness between fresh and frozen/thawed samples were greater in samples with INL/EVOO blends. Probably, the structural damage caused by freezing enabled the oil droplets to come close enough together to aggregate through steric and/or electrostatic forces.[40] Variations in BE firmness based on a freeze/thaw cycle showed that the BE firmness value developed differently for MPA and MPB samples (Fig. 5c). Freezing and thawing significantly reduced sample firmness in the MPA samples but significantly increased it in MPB samples. This difference can be explained if we consider that much stronger and more cohesive networks are formed when solutions of XG are frozen and thawed.[41] The effect of XG may be explained by amylose/XG interactions, which compete against amylose/amylose interactions, retarding or even preventing retrogradation. Also, the addition of small amounts of XG has been reported to significantly improve freeze/thaw stability of white sauces made with starches from different sources.[29]

E_w value variations for different INL:EVOO ratios of both FMP and F/TMP samples are shown in Fig. 5d. In both FMP and F/TMP samples, at a fixed total concentration, the highest and lowest E_w values were registered in samples with addition ratios of 60:0 and 0:60, respectively. Furthermore, in the FMP products the water holding capacity (WHC) decreased linearly with increasing INL content (0:60, 15:45, 30:30, and 45:15 ratios), probably due to large INL particles occupying the interchain spaces and displacing the water. Nevertheless, EVOO by itself did not affect the WHC of MP systems (Table 4). Besides, E_w was greater in the FMP samples than in their F/TMP counterparts in all cases. This is related in part to water loss occurring in the frozen/thawed samples through recrystallization and sublimation phenomena. However, these results also suggest that cooling prior to freezing, as well as freezing itself, might have favored conformational changes in the INL molecules, which in turn would have resulted in a smaller solid particle size and a larger surface exposed to interaction with water.[42] This could account for the superior water retention detected in the F/TMP samples. Moreover, as long-chain INL particles are only held together by physical interaction between molecules,[43] the mechanical strength of the crystallized INL particles might have been too low to support the stresses caused by ice crystal growth during freezing. Also, in these systems there could have been sedimentation of INL crystals as a result of decreasing temperature[44] and subsequent recrystallization during thawing and heating. After freezing, enough water may be present to allow a small fraction of INL to recrystallize with different solubility properties.

After a complete dependence study, which was carried out on the sensory attribute scores versus instrumental texture measurements, low correlations between instrumental and sensory ratings were found. Previous publications by other researchers generally agreed on good to excellent correlations for hardness (based on calculated "r" values),[7] which contrasts with correlations for other parameters that are usually mediocre and product dependent. In this study, when considering different subgroups separately, relatively high correlations with sensory firmness scores were found in the case of BE firmness, so

that relationships were statistically significant as linear functions. The best correlation was found between BE firmness and perceived firmness when the F/TMP samples with added cryoprotectants were considered separately ($R^2 = 0.88$). Differences in thickness observed among samples were explained by BE firmness, but not the variation in other surface and geometrical textural attributes, determining sample creaminess. Certainly, although mechanical and rheological properties are the predominant stimuli affecting texture perception in most foods, results indicate that in the case of MP samples, matching rheological behavior with perceived texture is not guaranteed, as reported by Bayarri et al.[28]

CONCLUSIONS

Mechanical texture properties have confirmed that both INL and EVOO can be considered as soft fillers suspended and entrapped in a rigid amylose/amylopectin matrix, respectively. The most obvious difference was observed between 0:0 control and samples containing 15:45 and 30:45 ratios, which was ascribed mainly to the fact that the samples containing higher EVOO concentrations received lower granularity scores. In FMP samples, the sensory texture profile of products with an added 30:30 ratio was similar to that of the product without added ingredients. This result has important consequences for the formulation of MP with added inulin and extra virgin olive oil blends, since the food industry places particular emphasis on the development of foods that have the same desirable quality attributes as the original product. On the contrary, in both F/TMP and MPA samples considered separately, the texture profile of the product without added ingredients was very different from that of MP samples containing INL and EVOO, whether added singly or in associated blends. If the product is to be frozen, and therefore contains cryoprotectants, κ-C and XG mask the effect of adding different INL/EVOO blends on the texture profile of the MP samples, probably due to the water holding capacity conferred by XG. PCA of the total dataset and FMP, F/TMP, and MPA samples considered separately showed that component 1 served as an index of the mechanical behavior and moistness of the product, whereas when MPB samples were analyzed separately, the first principal component served as an index of the roughness/smoothness in response to reduced starch retrogradation in the presence of κ-C and XG. Although the level of consonance between panelists was acceptable, better results could have been achieved with more training in the use of stickiness, adhesiveness, ease of swallowing, and palate coating. Furthermore, the results suggest that there is an overlap between moisture (1) and moisture (2), between fibrousness (1) and fibrousness (2), and between stickiness and adhesiveness. Certainly, more work is needed on reselection of some sensory attributes.

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